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(54) **WASTE HEAT RECOVERY HYBRID POWER DRIVE**

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(57) **ABSTRACT**

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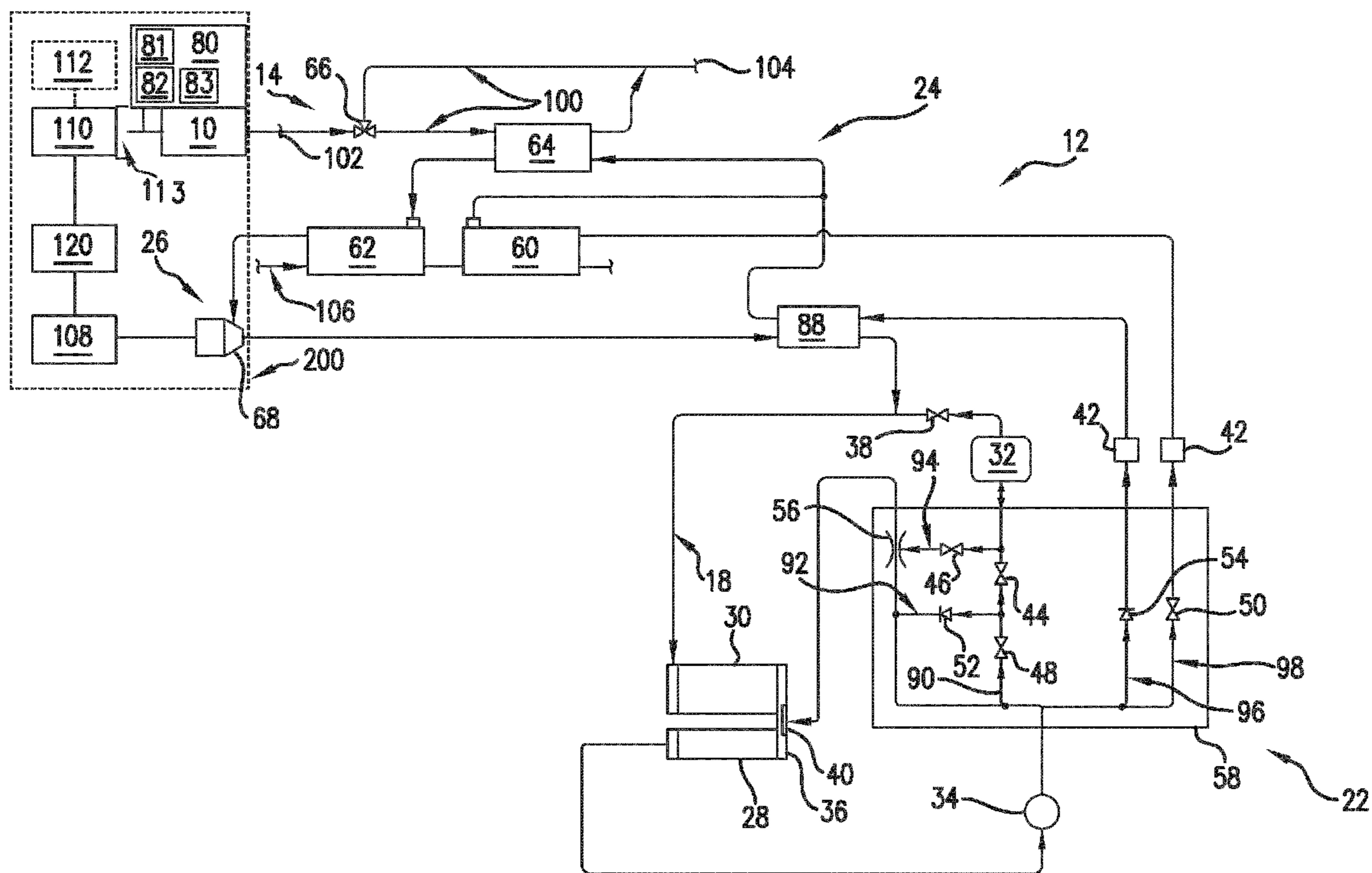
A system includes an internal combustion engine; a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the energy conversion system is structured to generate power from the extracted heat energy; a gear box operatively coupled to an output of the energy conversion system; and an alternator operatively coupled to the gear box and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

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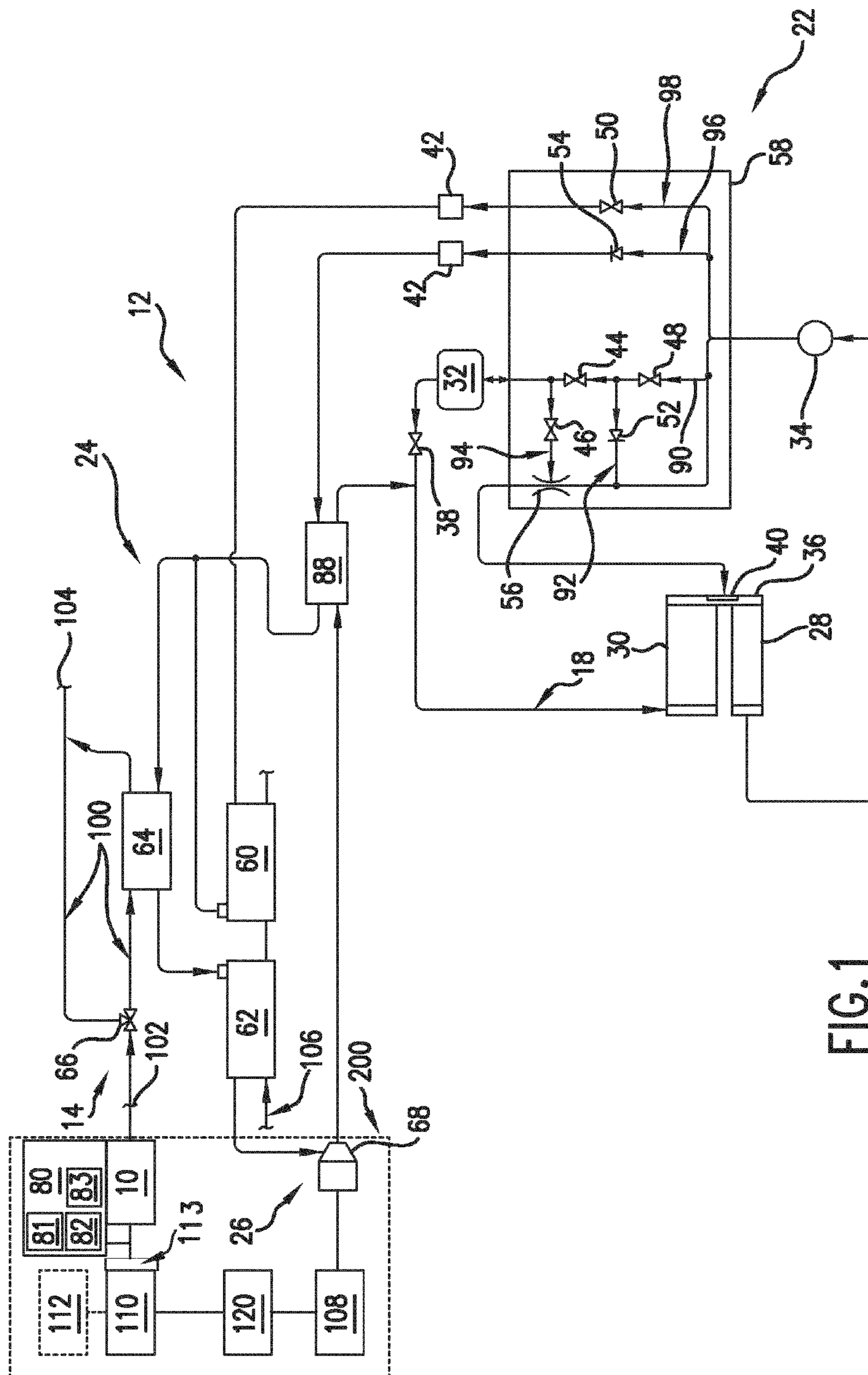
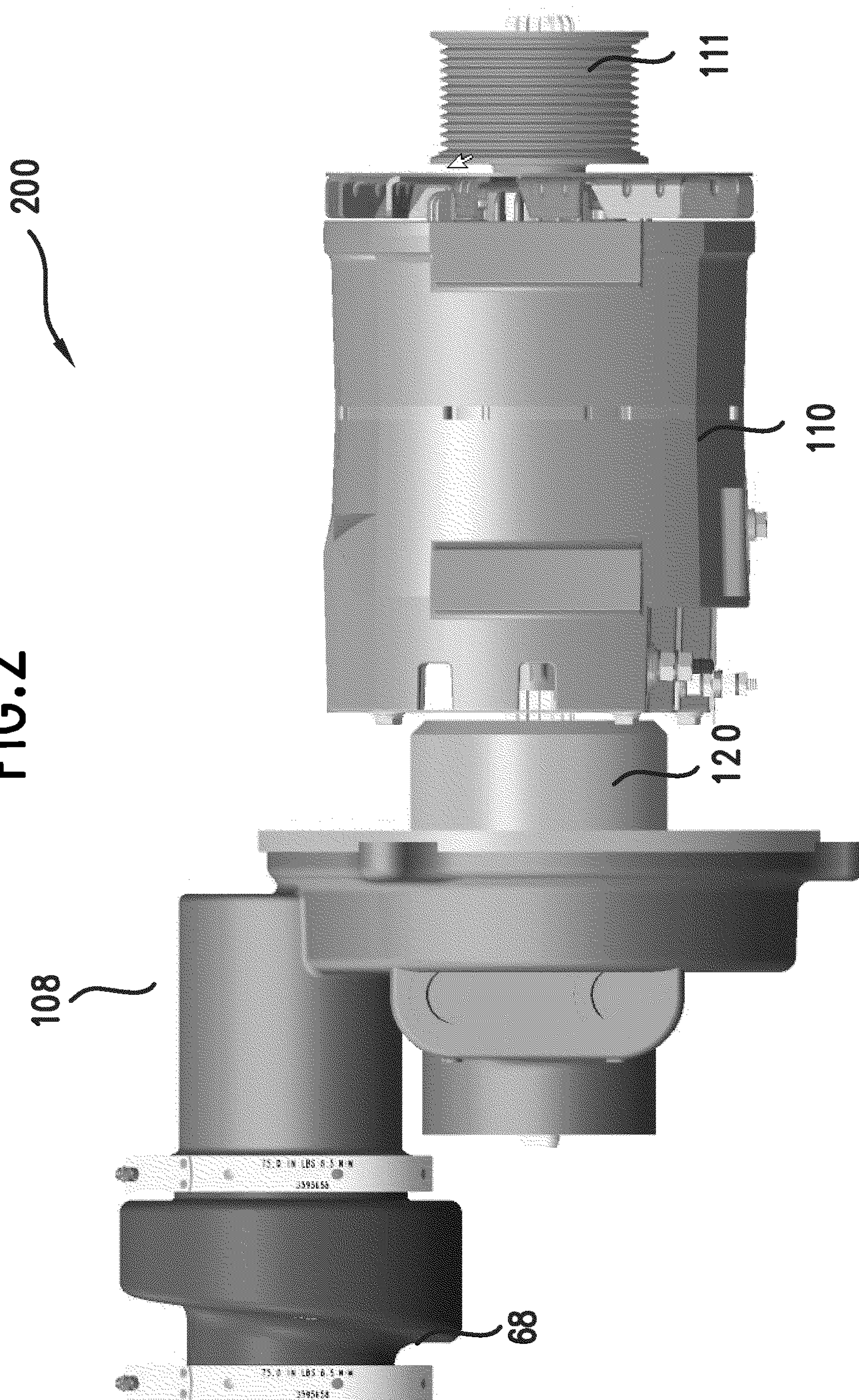


FIG.1

FIG. 2



WASTE HEAT RECOVERY HYBRID POWER DRIVE

TECHNICAL FIELD

[0001] This disclosure relates to Waste Heat Recovery (WHR) systems. More particularly, the disclosure relates to WHR systems used with hybrid vehicles.

BACKGROUND

[0002] A waste heat recovery (WHR) system recovers heat energy from an internal combustion engine that would otherwise be lost. The more waste heat energy extracted from an internal combustion engine by a WHR system, the greater the potential efficiency of the engine. In other words, rather than the extracted heat being lost, the extracted heat energy may be repurposed to, e.g., supplement the power output from the internal combustion engine thereby increasing the efficiency of the system. However, the WHR system requires energy to operate, such as the energy required to operate a feedpump to pump a working fluid through the WHR system. The energy required to operate the WHR system represents a loss to the efficiency gained from the WHR system.

SUMMARY

[0003] One embodiment relates to a vehicle. The vehicle includes an internal combustion engine; a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the energy conversion system is structured to generate power from the extracted heat energy; a gear box operatively coupled to an output of the energy conversion system; and an alternator operatively coupled to the gear box and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system. In one configuration, the vehicle is structured as a hybrid vehicle. In this configuration, the vehicle includes an electric power system structured selectively power the vehicle with or without assistance from the internal combustion engine. In this configuration, the alternator is structured to provide at least a portion of the produced electrical energy to the electrical power system. Advantageously, the provided electrical energy stems from recovered waste heat energy, which increases the relative efficiency of the vehicle.

[0004] Another embodiment relates to a system. The system includes an internal combustion engine; a waste heat recovery system having a working fluid circuit, a fluid management system positioned along the working fluid circuit that utilizes a working fluid, a heat exchange system positioned along the working fluid circuit, and a feedpump positioned along the working fluid circuit and structured to move the working fluid through the working fluid circuit; an energy conversion system positioned along the working fluid circuit downstream from the heat exchange system and upstream from the fluid management system, wherein the energy conversion system is structured to generate power from heat energy extracted from the engine via the waste heat recovery system; a gear box operatively coupled to an

output of the energy conversion system; a coupling structured to selectively receive the output of the energy conversion system; and an alternator operatively coupled to the coupling and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

[0005] Still another embodiment relates to a method. The method includes providing an internal combustion engine; providing a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the energy conversion system is structured to generate power from the extracted heat energy; and providing an alternator operatively coupled to the energy conversion system and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

[0006] Advantages and features of the embodiments of this disclosure will become more apparent from the following detailed description of exemplary embodiments when viewed in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a schematic of an internal combustion engine with a WHR system, according to an example embodiment.

[0008] FIG. 2 is a schematic diagram of an alternator, a coupling, a gearbox, and an expander used with WHR and engine system of FIG. 1, according to an example embodiment.

DETAILED DESCRIPTION

[0009] Referring to the Figures generally, various embodiments disclosed herein relate to systems and methods of outputting two forms of energy from a WHR system. According to the present disclosure, a system includes an engine, WHR system, an alternator, and a coupling to connect or couple the WHR system to the alternator. The WHR system extracts power from the WHR working fluid and outputs it in the form of a torque on a rotating shaft. Via the coupling, the torque on the rotating shaft is transferred to the alternator. The alternator may be part of a front end accessory drive (FEAD) system, such that the alternator powers front end accessories such as water pumps, power steering pumps, compressors, etc. The alternator may also receive power from the crankshaft of the engine. According to the present disclosure, the alternator consumes or utilizes some of the power extracted by the WHR system to generate electrical energy while the remainder or most of the remainder of the extracted energy is absorbed by the engine via the FEAD system through the crankshaft (i.e., the dual or two forms of energy).

[0010] Advantageously, by coupling the WHR system with the alternator, otherwise lost heat energy may be used to generate electrical energy. According to one embodiment, the present disclosure is implemented with a hybrid vehicle (vehicles powered by two different types of energy, such as

electrical energy from an electrical motor and chemical energy via combustion in an internal combustion engine). Beneficially, relatively more electrical energy may be generated to power the electrical motor of the hybrid vehicle than in conventional hybrid vehicles via the coupling to the alternator. This provides a technical advantage over current hybrid vehicle technology, which may be appealing to consumers. These and other features of the present disclosure are more fully described herein below.

[0011] Referring now to FIG. 1, an engine 10 and waste heat recovery (WHR) system is shown, according to one embodiment. It should be noted that the engine 10 and WHR system 12 shown in FIG. 1 is an example configuration. Other configurations may include or exclude other and different components. For example, in some embodiments, the exhaust gas recirculation (EGR) system 100 may be excluded from the system. Similarly, in other embodiments, the exhaust system may include one or more aftertreatment components, such as a diesel oxidation catalyst, a diesel particulate filter, and a selective catalytic reduction catalyst. However, the principles and disclosure described herein is still applicable to these variations. Therefore, all of these variations are intended to fall within the spirit and scope of the present disclosure.

[0012] In the example depicted in FIG. 1 (and FIG. 2), all of the components depicted are embodied in a vehicle. The vehicle 100 may be an on-road or an off-road vehicle including, but not limited to, line-haul trucks, mid-range trucks (e.g., pick-up truck), sedans, coupes, compacts, sport utility vehicles, and any other type of vehicle that utilizes cruise control systems.

[0013] As shown, the vehicle is structured as a hybrid vehicle (e.g., a vehicle that selectively uses two different energy sources to propel the vehicle). The vehicle includes an engine 10 structured as an internal combustion engine. The internal combustion engine may include a spark-ignition engine and a compression ignition engine. Accordingly, the engine 10 may be fueled by any fuel, such as gasoline, diesel, and ethanol. In operation, the engine 10 receives a chemical energy input (e.g., a fuel such as gasoline, diesel, etc.) and combusts the fuel to generate mechanical energy, in the form of a rotating crankshaft. A transmission (not shown) receives the rotating crankshaft and manipulates the speed of the crankshaft to affect a desired drive shaft speed. The rotating drive shaft is received by a differential, which provides the rotation energy of the drive shaft to the final drive (e.g., wheels, etc.). The final drive then propels or moves the vehicle.

[0014] The vehicle also includes an electric power system 80. The electric power system 80 is structured to selectively power or propel the vehicle in combination with or separate from the engine 10. The electric power system 80 includes one or more energy storage devices 81 (e.g., batteries) and an electric motor 82. The electric motor 82 receives power from the one or more energy storage devices 81 to selectively propel the vehicle. The components shown as part of the electric power system 80 are not meant to be limiting as the electric power system may include additional features with additional functionality. For example, components relating to a regenerative braking system may also be included in the electric power system. Accordingly, the electric power system 80 is meant to be broadly interpreted.

[0015] According to one embodiment, the WHR system 12 described herein is a Rankine cycle waste heat recovery

system, or an organic Rankine cycle if the working fluid is an organic high molecular mass fluid with a liquid-vapor phase change that is lower than the water-steam phase change. Examples of Rankine cycle working fluids, organic and inorganic, include Genetron® R-245fa from Honeywell, Therminol®, Dowtherm J™ from Dow Chemical Co., Fluorinol® from American Nickeloid, toluene, dodecane, isododecane, methylundecane, neopentane, neopentane, octane, water/methanol mixtures, or steam.

[0016] As shown, the WHR system 12 includes a WHR circuit 18, along which are positioned a fluid management system 20, a fluid control portion 22, a heat exchange system 24, and an energy conversion system 26. The fluid management system 20 provides storage or containment, and cooling for a working fluid of the WHR system 12. The fluid control portion 22 regulates the flow of the working fluid throughout the WHR system 12. The heat exchange system 24 provides cooling to certain systems of the engine 10 and serves to heat the working fluid to permit the working fluid to drive an energy conversion system 26, extracting useful work or energy from the waste heat created by the engine 10.

[0017] The fluid management system 20 includes a sub-cooler 28, a condenser 30, a receiver 32, and a feedpump 34. The receiver 32 serves primarily as a reservoir for the WHR system 12. The condenser 30 serves to convert gaseous working fluid to liquid working fluid. The sub-cooler 28 provides cooling to the liquid working fluid. The condenser 30 may be integral with sub-cooler 28, may connect to sub-cooler 28 by way of WHR circuit 18, or may be commonly mounted with sub-cooler 28 on a common base 36, which may include a plurality of fluid flow paths (not shown) to fluidly connect the condenser 30 to the sub-cooler 28. The receiver 32 may be physically elevated higher than sub-cooler 28, and may be connected to sub-cooler 28 through fluid control portion 22. The top of receiver 32 includes a vent that may be opened to the condenser 30 by way of a vent valve 38. A fluid level sensor 40 is positioned along WHR circuit 18 in a location suitable to determine the level of the liquid working fluid in sub-cooler 28 and condenser 30. The feedpump 34 is positioned along WHR circuit 18 downstream from sub-cooler 28 and upstream from fluid control portion 22. The fluid management system 20 may also include one or more filter driers 42 positioned along WHR circuit 18 downstream from fluid control portion 22. Alternatively, the filter drier 42 may be positioned downstream from the feedpump 34 and upstream from the fluid control portion 22. All such variations are intended to fall within the spirit and scope of the present disclosure.

[0018] The fluid control portion 22 includes a plurality of valves and an ejector 56 configured to regulate flow as needed throughout WHR system 12. The valves include actuated on-off valves 44 and 46, actuated proportional valves 48 and 50, actuated vent valve 38, and passive check valves 52 and 54. In one embodiment, the ejector 56 is a passive device and operates in conjunction with certain valves to draw liquid working fluid from receiver 32. Many of the valves and ejector 56 may be included within a valve module or body 58. The function of the various valves and ejector 56 is to control the flow of working fluid in WHR system 12, which also controls the heat transferred to and from the working fluid flowing through WHR circuit 18. Though electrically actuated valves 38, 44, 46, 48, and 50 may be described as on-off or proportional valves, this description is for convenience in the context of the exem-

plary embodiment. The on-off valves may be proportional valves and the proportional valves may be modulated valves capable of opening and closing rapidly to adjust the amount of working fluid flowing through the valves.

[0019] The heat exchange system 24 includes a recuperator 88, an EGR boiler 60, an EGR superheater 62, an exhaust heat exchanger 64, and an exhaust control valve 66. The EGR boiler 60 provides the ability to regulate the temperature of an EGR gas by transferring heat from the EGR gas to the working fluid. It should be understood that the term “EGR boiler” is used for the sake of convenience. EGR boiler 60 may serve more than one function for system, such as cooling the EGR gas and transferring heat from the EGR gas to the working fluid of WHR system 12. The exhaust heat exchanger 64 permits the controlled transfer of heat from the exhaust of the engine 10 to the working fluid. The amount of heat available to exhaust heat exchanger 64 is determined by exhaust control valve 66. The EGR superheater 62 transfers additional heat energy from the EGR gas to the working fluid, which is in a gaseous state when it enters EGR superheater 62. The EGR superheater 62 is positioned along WHR circuit 18 downstream from exhaust heat exchanger 64 and upstream from condenser 30.

[0020] The exhaust heat exchanger 64 is positioned along the exhaust gas circuit 100. The exhaust gas circuit 100 fluidly connects an upstream aftertreatment system 102 to exhaust heat exchanger 64. The exhaust control valve 66 is positioned between aftertreatment system 102 and exhaust heat exchanger 64. Both the exhaust control valve 66 and the exhaust heat exchanger 64 are fluidly connected on their downstream sides by exhaust gas circuit 100 to an atmospheric vent 104, which may be a tailpipe, exhaust pipe, exhaust stack, or the like.

[0021] The EGR superheater 62 and EGR boiler 60 are connected to a portion of an EGR circuit 106. EGR gas flows along EGR circuit 106 into the EGR superheater 62 and then downstream from EGR superheater 62 into the EGR boiler 60. From the EGR boiler 60, the EGR gas flows downstream along EGR circuit 106. The EGR superheater 62 and the EGR boiler 60 serve as heat exchangers for the EGR circuit 106, providing a cooling function for the EGR gas flowing through EGR superheater 62 and EGR boiler 60. The EGR superheater 62 and the EGR boiler 60 also serve as heat exchangers for the WHR circuit 18, raising the temperature of working fluid flowing through EGR boiler 60 and through the EGR superheater 62.

[0022] As shown, the fluid control portion 22 may include a plurality of parallel flow path portions formed along the WHR circuit 18 that connect the feedpump 34 to various elements of the WHR system 12. A first flow path portion 90 fluidly connects the downstream side of the feedpump 34 to the receiver 32. Positioned along the first flow path portion 90 between the feedpump 34 and the receiver 32 is a proportional valve 48, which is downstream from the feedpump 34 and upstream from the receiver 32. Positioned along the first flow path portion 90 between the proportional valve 48 and the receiver 32 is an on-off valve 44. Though not part of the first flow path portion 90, a vent valve 38 is positioned along the WHR circuit 18 between the receiver 32 and the condenser 30. The purpose of the vent valve 38 is to permit vapor to move into and out from the receiver 32 as liquid working fluid is moved out from and into the receiver 32 along the first flow path portion 90.

[0023] A second flow path portion 92 extends from a location along the first flow path portion 90 between the proportional valve 48 and the on-off valve 44 to fluidly connect to the sub-cooler 28 and the condenser 30. The passive check valve 52 is positioned along the second flow path portion 92, and the ejector 56 is positioned along the second flow path portion 92 between the passive check valve 52 and the sub-cooler 28 and/or the condenser 30, downstream from the passive check valve 52 and upstream from the sub-cooler 28 and/or the condenser 30. The first flow path portion 90 is also connected to the second flow path portion 92 by a connection path portion 94, which extends from a location between the on-off valve 44 and the receiver 32 to the ejector 56. The on-off valve 46 is positioned along connection path portion 94.

[0024] A third flow path portion 96, which is parallel to the first flow path portion 90 and to the second flow path portion 92, fluidly connects the feedpump 34 to the recuperator 88. The passive check valve 54 is positioned along the third flow path portion 96, between the feedpump 34 and the recuperator 88. The recuperator 88 is connected on a downstream side to the exhaust heat exchanger 64. The filter drier 42 may be positioned along the WHR circuit 18 between the recuperator 88 and the passive check valve 54. The recuperator 88 is also positioned along the WHR circuit 18 between the energy conversion system 26 and the condenser 30, downstream from the energy conversion system 26 and upstream from the condenser 30.

[0025] A fourth flow path portion 98, which is parallel to the first flow path 90, second flow path portion 92, and third flow path portion 96, fluidly connects the feedpump 34 to the EGR boiler 60. The exhaust heat exchanger 64 is positioned downstream from the EGR boiler 60 and the recuperator 88. Thus, any working fluid flow along third flow path portion 96 and working fluid flow along fourth flow path portion 98 converges prior to entry into the exhaust heat exchanger 64. The proportional valve 50 is positioned along fourth flow path portion 98 downstream from the feedpump 34 and upstream from the engine heat exchanger 60. A filter drier 42 may be positioned along the WHR circuit 18 downstream from the proportional valve 50 and upstream from the EGR boiler 60.

[0026] With the components of the WHR system 12 described above, operation of the WHR system 12 may be described as follows. The sub-cooler 28 stores the liquid working fluid. The feedpump 34 pulls or draws liquid working fluid from the sub-cooler 28. The feedpump 34 then forces liquid working fluid downstream to the valve module 58. In the valve module 58, the flow of liquid working fluid may be directed to one of four parallel flow path portions. As described above, the first flow path portion 90 connects the feedpump 34 to the receiver 32, the second flow path portion 92 connects the feedpump 34 to the condenser 30/sub-cooler 28, the third flow path portion 96 connects the feedpump 34 to the recuperator 88, and the fourth flow path portion 98 connects feedpump 34 to EGR boiler 60. It should be understood that these flow paths are exemplary as more or less flow paths may be used in other systems and arrangements.

[0027] During normal operation of the engine 10, the proportional valve 48 is at least partially open to permit liquid working fluid to flow into the first flow path portion 90 and then into the second flow path portion 92, flowing through the passive check valve 54, which may have a

cracking or opening pressure threshold (e.g. five psi), so that liquid working fluid flows through the second flow path portion to the sub-cooler 28, thus forming a continuous loop of flowing liquid working fluid when check valve 52 opens. If the proportional valve 48 is opened and on/off valve 44 is closed, liquid working fluid flows into the first flow path portion 90 into the second flow path portion 92, which may be used to prevent the two-phase working fluid flow, i.e., liquid and gas, from reaching the energy conversion system 26. If the on-off valve 44 is opened when proportional valve 48 is opened, the on-off valve 46 is closed, and the vent valve 38 is opened, the cracking pressure of the check valve 52 causes liquid working fluid to flow upwardly along first flow path portion 90 to the receiver 32. The flow of fluid into the receiver 32 causes the level of liquid working fluid in the receiver 32 to increase, and causes the level of liquid working fluid in the sub-cooler 28 and/or the condenser 30 to decrease. Thus, in this valve configuration the feedpump 34 may be connected simultaneously to the sub-cooler 28 and to the receiver 32.

[0028] If the on-off valve 46 is open, the on-off valve 44 is closed, and the vent valve 38 is open while liquid working fluid flows from the feedpump 34 along first flow path portion 90 into the second flow path portion 92 and then into sub-cooler 28 and/or condenser 30, then the receiver 32 is connected to the sub-cooler 28 and/or the condenser 30 along a portion of the WHR circuit 18 that is parallel to the portion of the WHR circuit 18 that connects the feed pump 34 to the sub-cooler 28 and/or the condenser 30. In this valve configuration, liquid working fluid will be drawn from receiver 32, flowing through a portion of the first flow path portion 90 through the on-off valve 46, which is positioned along the connection path portion 94, into the ejector 56. The liquid working fluid then flows downstream from the ejector 56 to the sub-cooler 28 and the condenser 30, increasing the level of liquid working fluid in the sub-cooler 28 or in the condenser 30. The level of liquid working fluid may vary sufficiently that the condenser 30 may contain some liquid working fluid. The increase in the level of the liquid working fluid in sub-cooler 28 increases sub-cooling, adjusting the saturation temperature of the liquid working fluid. The vent valve 38 is normally open during operation of engine 10, which permits vapor to flow to and from the top portion of receiver 32 to and from a top portion of condenser 30, permitting the level of liquid working fluid in receiver 32 to increase or decrease. Once the level of liquid working fluid has been increased in sub-cooler 28 and/or condenser 30 a desirable amount, the on-off valve 46 is closed, stopping flow from receiver 32 through connection path portion 94.

[0029] Liquid working fluid flows along the third flow path portion 96 based on the opening of proportional valve 50 positioned along the fourth flow path portion 98. Passive check valve 54 creates a backpressure along the upstream portion of third flow path portion 96, which biases the flow of liquid working fluid along fourth flow path portion 98. By partially closing the proportional valve 50, the backpressure along the upstream portion of the fourth flow path portion 98 increases, until passive check valve 54 cracks or opens under the increased backpressure from the proportional valve 50. Relatively small amounts of liquid working fluid normally flow through the first flow path portion 90 and the second flow path portion 92, so most of the liquid working fluid provided to the WHR circuit 18 by the feedpump 34 flows through the third flow path portion 96 and the fourth flow

path portion 98. Flow of working fluid through the third flow path portion 96 and the fourth flow path portion 98 converges upstream from the exhaust heat exchanger 64.

[0030] Cooling of exhaust gas in the exhaust heat exchanger 64 is an optional function that may be reduced in favor of cooling of EGR gas in the EGR boiler 60. Thus, the configuration of these components is advantageous in providing priority cooling to the EGR gas. Additional heat may then be added to the working fluid as needed in the exhaust heat exchanger 64 and the EGR superheater 62 by the WHR system 12 to obtain optimal superheating of the working fluid. The working fluid, which is in a gaseous state because of heat transfer from the above-described heat exchangers, flows from exhaust gas heat exchanger 64 into the EGR superheater 62, where additional heat energy is added to the gaseous working fluid. The superheated gaseous working fluid flows from the EGR superheater 62 into energy conversion device 68.

[0031] The flow of the working fluid through the WHR system 12 extracts heat energy. As described herein, the heat energy may be used by the energy conversion system 26 to transfer energy to another system or device.

[0032] It should be understood that in certain embodiments, the WHR system 12 further includes a controller structured to perform certain operations to control or regulate the flow of the working fluid through the system 12. In certain embodiments, the controller forms a portion of a processing subsystem including one or more computing devices having memory, processing, and communication hardware. The controller may be a single device or a distributed device, and the functions of the controller may be performed by hardware and/or as computer instructions on a non-transient computer readable storage medium. In certain embodiments, the controller includes one or more modules structured to functionally execute the operations of the controller. Modules may be implemented in hardware and/or as computer instructions on a non-transient computer readable storage medium, and modules may be distributed across various hardware or computer based components. To facilitate the accurate control by the controller, the WHR system 12 may include one or more sensors strategically positioned and communicatively coupled to the controller. The sensors may include, but are not limited to, temperature sensors, pressure sensors, flow sensors, etc. Accordingly, example and non-limiting module implementation elements include sensors, like described above, providing any value used by the controller, sensors providing any value that is a precursor to a value determined, datalink and/or network hardware including communication chips, oscillating crystals, communication links, cables, twisted pair wiring, coaxial wiring, shielded wiring, transmitters, receivers, and/or transceivers, logic circuits, hard-wired logic circuits, reconfigurable logic circuits in a particular non-transient state configured according to the module specification, any actuator including at least an electrical, hydraulic, or pneumatic actuator, a solenoid, an op-amp, analog control elements (springs, filters, integrators, adders, dividers, gain elements), and/or digital control elements.

[0033] Referring now to FIG. 1 in connection with FIG. 2, description of the components located in section 200 is now explained. As mentioned above, the WHR system 12 is operatively coupled to an energy conversion system 26. The energy conversion system 26 is structured to produce additional work or transfer energy to another device or system.

The energy conversion system **26** is shown to include an energy conversion device **68**. The energy conversion system **26** may be a turbine, piston, scroll, screw, or other type of expander device that moves, e.g., rotates, as a result of expanding working fluid vapor to provide additional work. Alternatively, energy conversion system **26** can be used to transfer energy from one system to another system (e.g., to transfer heat energy from WHR system **12** to a fluid for a heating system). The energy conversion device **68** is positioned along the WHR circuit **18** and is downstream from the EGR superheater **62** and upstream from the condenser **30** in this embodiment.

[0034] According to the present disclosure, the energy conversion device **68** is operatively coupled to an energy transfer device, shown as gear box **108**. In this embodiment, the energy conversion device **68** is structured as an expander (FIG. **2**). The expander receives and expands the working fluid from the WHR system **12** to generate power in the form of a rotating shaft. The rotating shaft is received by the gear box **108**. The gear box **108** is structured to include one or more gear trains corresponding to one or more gear ratios (expander shaft input-to-gear box output). The gear box **108** is structured to reduce a speed of rotation of the shaft of the expander **68** to an operating shaft speed of the shaft of the alternator **110**. For example, the alternator **110** may have a prescribed operating shaft speed. The gear box **108** is structured to match or substantially match the expander shaft speed with that operating speed of the alternator shaft. Therefore, in some embodiments, the gear box **108** may act like an overdrive and increase the expander shaft speed while in other embodiments the gear box **108** may reduce the expander shaft speed to align or substantially align with the intended operating speed of the alternator **110** shaft. In this regard, the system of the present disclosure may maintain or nearly maintain efficient operation of the alternator **110**. According to another embodiment, the alternator **110** may utilize electric load balancing (e.g., altering the torque applied to the shaft of the alternator **110** by selectively adjusting the current in the windings) to control a speed of the alternator shaft to enhance speed matching between the expander **68** and the alternator **110**. According to an alternate embodiment, the gear box **108** may be removed from the system, such that the alternator **110**, via electric load balancing, synchronizes or substantially synchronizes the speed of the expander shaft to the alternator shaft.

[0035] The alternator **110** is structured as an on-engine **10** alternator. Accordingly, the alternator **110** may be coupled to a crankshaft of the engine **10**. In other embodiments, the alternator **110** may be replaced with a high capacity alternator for additional electrical power and charging capacity.

[0036] As shown, the alternator **110** is coupled to a coupling **120**. The coupling **120** is operatively coupled to both the alternator **110** and the gear box **108**. In one embodiment, the coupling **120** is structured as a shaft coupling thereby permitting the coupling of a shaft of the alternator **110** to an output shaft of the gear box **108**. In one embodiment, the coupling **120** may selectively engage with at least one of the alternator **110** shaft and the output shaft of the gear box **108**. For example, the coupling **120** may be electromechanically actuated via the controller (described above). In this regard, the coupling **120** may selectively transfer power from the expander **68** to the alternator **110** (or, in certain embodiments, vice versa).

[0037] The alternator **110** is shown to include a front end accessory drive (FEAD) pulley **111**. The FEAD pulley **111** operatively couples (e.g., via one or more belts, such as a serpentine belt and a fan belt, gear chains, etc.) to one or more front end accessories **112** in the vehicle. In this regard, according to another embodiment, the pulley **111** may be structured gear. The gear may be operatively coupled to the engine **10** or integrated into the engine gear train. All such configurations for the pulley **111** are intended to fall within the spirit and scope of the present disclosure. The one or more front end accessories **112** may include, but are not limited to, a water pump, an air conditioning compressor, and a power steering pump. The one or more front end accessories **112** is shown in a dashed line on FIG. **1** to indicate that the alternator **110** may selectively power some of the accessories.

[0038] According to one embodiment, the alternator **110** is coupled to a clutch **113**, where the clutch **113** is coupled to the engine **10**. The clutch **113** may be any type of clutch mechanism that can selectively couple and decouple the alternator **110** to and from the engine **10**. In certain embodiments, the clutch **113** may be actuated via the controller (such as the one described above) to selectively control when the alternator (e.g., a shaft of the alternator) is coupled to the engine **10** and, therefore, driven at least in part by the engine **10**. In this regard, the alternator **110** shaft speed may be controlled via operation of the clutch. This speed control feature may be used independent of or in combination with the electric load balancing of the alternator **110** and operation of the gear box **108**.

[0039] In one embodiment, like shown in FIG. **1**, the alternator **110** is also operatively coupled to the electric power system **80**. The coupling may be via any fashion (such as via a belt, electrical contacts, etc.). In one embodiment, the alternator **110** is electrically coupled to the one or more energy storage devices **81**, such that the alternator **110** may selectively charge the one or more energy storage devices **81**. In another embodiment, the alternator **110** is directly coupled to the electrical motor **82**, such that the alternator **110** directly powers the electrical motor **82**. In still another embodiment, the alternator **110** is coupled to a variable energy dissipation device **83** (e.g., a load bank such as a resistive load bank, etc.) in the vehicle that may be used for a variety of uses in the vehicle, such as braking. In other variations, the alternator **110** may be selectively coupled to each of the one or more energy storage devices **81** and the electrical motor **82**. Therefore, in operation, some of the generated power from the extracted waste heat is used to produce electrical energy by the alternator **110** which may be provided to the electric power system. In other embodiments, the produced electrical energy may be provided to other places as well (e.g., one or more electrically-actuated sensors or valves, etc.).

[0040] With reference primarily to FIG. **2**, operation of the section **200** may be described as follows. The WHR system **12** directs working fluid to the energy conversion device, which is embodied as an expander **68** in FIG. **2**. The expander **68** is any device which extracts power from the waste heat recovery working fluid. The expander **68** generates power from the heat energy recovered from the engine **10**. The generated output power is in the form of a torque on a rotating shaft of the expander **68**. The rotating shaft is received by the gear box **108**. The gear box **108** matches the expander rotating shaft speed to the alternator **110** operating

shaft speed for a given engine. That is, the alternator shaft speed may vary based on the engine. In other embodiments, and as described above, a clutch such as clutch **113** may couple the alternator to the engine to selectively control the alternator shaft speed to enhance speed matching with the expander. The gear box **108** output shaft is coupled to the alternator shaft by coupling **120**.

[0041] Thus, the alternator **110** may receive power from at least one of the engine **10** (e.g., a crankshaft) and via the WHR system **12** via the coupling **120**, gear box **108**, and energy conversion device **68**. In this regard, the alternator **110** consumes WHR power to generate electrical energy and the remainder is transferred back to the engine via the FEAD through the crankshaft of the engine. Advantageously, this additional amount of energy from the WHR system **12** may be used to power or charge the electrical power system **80** of a hybrid vehicle. This supplemental energy from the WHR system **12** that is routed via the alternator **110** is an additional energy source that may increase the efficiency of the hybrid vehicle of the present disclosure.

[0042] It should be understood that while the systems described herein relate to the use of shaft couplings and gear boxes, Applicants contemplate other energy transfer mechanism (e.g., inductive energy transfer, etc.) that may be used in addition or in place of the gear box and shaft coupling. Accordingly, many different mechanisms may be contemplated by those of ordinary skill in the art that could serve as obvious replacements for the features and components described herein. These obvious variants are intended to fall within the spirit and scope of the present disclosure.

[0043] It should be noted that the term “example” as used herein to describe various embodiments is intended to indicate that such embodiments are possible examples, representations, and/or illustrations of possible embodiments (and such term is not intended to connote that such embodiments are necessarily extraordinary or superlative examples).

[0044] While various embodiments of the disclosure have been shown and described, it is understood that these embodiments are not limited thereto. The embodiments may be changed, modified and further applied by those skilled in the art. Therefore, these embodiments are not limited to the detail shown and described previously, but also include all such changes and modifications.

[0045] Additionally, the format and symbols employed are provided to explain the logical steps of the schematic diagrams and are understood not to limit the scope of the methods illustrated by the diagrams. Although various arrow types and line types may be employed in the schematic diagrams, they are understood not to limit the scope of the corresponding methods. Indeed, some arrows or other connectors may be used to indicate only the logical flow of a method. Additionally, the order in which a particular method occurs may or may not strictly adhere to the order of the corresponding steps shown.

What is claimed is:

1. A vehicle, comprising:

an internal combustion engine;

a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the

energy conversion system is structured to generate power from the extracted heat energy;

a gear box operatively coupled to an output of the energy conversion system; and

an alternator operatively coupled to the gear box and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

2. The vehicle of claim **1**, wherein the energy conversion system includes a waste heat recovery expander and the output is a shaft of the waste heat recovery expander.

3. The vehicle of claim **2**, further comprising a shaft coupling, wherein the shaft coupling selectively couples to the shaft of the waste heat recovery expander and to a shaft of the alternator.

4. The vehicle of claim **3**, wherein the gear box is structured to substantially match a speed of rotation of the shaft of the waste heat recovery expander to an operating shaft speed for the shaft of the alternator.

5. The vehicle of claim **1**, further comprising an electric power system, the electric power system structured to selectively power the vehicle in at least one of combination with and separate from the engine, wherein the electric power system includes at least one of a variable energy dissipation device, one or more energy storage devices, and an electric motor.

6. The vehicle of claim **5**, wherein the alternator is structured to selectively charge the one or more energy storage devices via the produced electrical energy.

7. The vehicle of claim **1**, wherein the alternator is a part of the front end accessory drive system, wherein the alternator includes a pulley structured to selectively power one or more accessories in the front end accessory drive system.

8. The vehicle of claim **7**, wherein the pulley is coupled to a clutch configured to selectively couple the pulley to the internal combustion engine, wherein the clutch is configured to selectively couple and decouple the pulley from the engine to at least partly control an operating shaft speed of a shaft of the alternator.

9. The vehicle of claim **8**, wherein the clutch is configured to control the operating shaft speed of the shaft of the alternator to substantially match a rotational speed for a shaft of a waste heat recovery expander included in the energy conversion system.

10. The vehicle of claim **7**, wherein the one or more accessories include a power steering pump, an air conditioning compressor, and a water pump.

11. A system, comprising:

an internal combustion engine;

a waste heat recovery system having a working fluid circuit, a fluid management system positioned along the working fluid circuit that utilizes a working fluid, a heat exchange system positioned along the working fluid circuit, and a feedpump positioned along the working fluid circuit and structured to move the working fluid through the working fluid circuit;

an energy conversion system positioned along the working fluid circuit downstream from the heat exchange system and upstream from the fluid management system, wherein the energy conversion system is structured to generate power from heat energy extracted from the engine via the waste heat recovery system;

a gear box operatively coupled to an output of the energy conversion system;

a coupling structured to selectively receive the output of the energy conversion system; and

an alternator operatively coupled to the coupling and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

12. The system of claim **11**, wherein the energy conversion system includes a waste heat recovery expander and the output is a shaft of the waste heat recovery expander.

13. The system of claim **12**, wherein the coupling is structured as a shaft coupling, wherein the shaft coupling selectively couples to the shaft of the waste heat recovery expander and a shaft of the alternator.

14. The system of claim **13**, wherein the gear box is structured to substantially match a speed of rotation of the shaft of the expander to an operating shaft speed for the shaft of the alternator.

15. The system of claim **13**, wherein the alternator is configured to substantially match a speed of rotation for the shaft of the alternator to a rotational speed of the shaft of the expander.

16. The system of claim **11**, further comprising an electric power system, the electric power system operable either with or separate from the engine, wherein the electric power system includes one or more energy storage devices and an electric motor.

17. The system of claim **16**, wherein the alternator is structured to selectively charge the one or more energy storage devices via the produced electrical energy.

18. The system of claim **11**, further comprising an exhaust gas recirculation (EGR) circuit, wherein the heat exchange system further includes an EGR boiler/superheater and a recuperator.

19. The system of claim **18**, wherein the fluid management system includes a condenser, a receiver, and a sub-cooler.

20. The system of claim **19**, wherein the fluid management system includes a valve module, wherein the valve module selectively facilitates provision of the working fluid to four flow paths in the waste heat recovery system.

21. A method, comprising:

providing an internal combustion engine;

providing a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the energy conversion system is structured to generate power from the extracted heat energy; and

providing an alternator operatively coupled to the energy conversion system and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

22. The method of claim **21**, further comprising providing a gear box and a coupling, wherein the energy conversion system is coupled to the gear box, which is coupled to the coupling, which is coupled to the alternator.

23. The method of claim **21**, wherein the energy conversion system includes a waste heat recovery expander having a shaft, wherein the shaft is received by the gear box.

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